IN THE *beginning there is parent rock, inert and dead. What kinds of rock are there? How are they turned into the parent material of soil and this into soil itself? In soil formation what part is played by climate, by living organisms, by the slope or relief of the land, by rains and rivers and wind and ice, and by time itself? This article discusses these questions. A somewhat more technical section at the end deals with the differences that characterize the various groups of soils.*

Formation of Soil

By H. G. Byers, Charles E. Kellogg, M. S. Anderson, *and* James Thorp [1]

SOILS are natural media for the growth of plants. They are mixtures of fragmented and partly or wholly weathered rocks and minerals, organic matter, water, and air, in greatly varying proportions, and have more or less distinct layers or horizons developed under the influence of climate and living organisms. The cross section of horizons from the surface to the parent material is known as the soil profile. The degree of profile development is dependent on the intensity of the activity of the different soil-forming factors, on the length of time they have been active, and on the nature of the materials from which the soils have developed. Soils are dynamic in character—they are constantly undergoing change—but they normally reach a state of near equilibrium with their environment, after a long period of exposure to a given set of conditions, and they may change but little during periods of hundreds or even thousands of years unless there is a change in the environment.

THE FACTORS OF SOIL GENESIS

True soil is the product of the action of climate and living organisms upon the parent material, as conditioned by the local relief. The length of time during which these forces are operative is of great importance in determining the character of the ultimate product. Drainage conditions are also important and are controlled by local relief, by the nature of the parent material or underlying rock strata, or by the amount of precipitation in relation to rate of percolation and

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run-off of water. There are, therefore, five principal factors of soil formation: (1) Parent material; (2) climate; (3) biological activity (living organisms); (4) relief; and (5) time. These soil-forming factors are interdependent, each modifying the effectiveness of the others. Thus, the character of the relief influences, through drainage and run-off, the effects of rainfall and of time. The character of the parent material modifies the effects of rainfall and relief of a given area. The character of the vegetation is, in part, determined by temperature and rainfall and in turn modifies the effects of these, particularly of rainfall. Despite these complex interrelationships, it is possible to gain a helpful insight into the question of soil formation by consideration of each of the formative factors separately.

FORMATION OF PARENT MATERIAL

The first step in the development of soil is the formation of parent material, accumulated largely through rock weathering. The parent rock is a relatively inert storehouse of future soil material rather than an active factor in soil formation. The distinguishing characteristics of the soils of the great soil groups are primarily due to the effects of climate and biological action on rocks, but many of their subdivisions owe their distinctive characteristics to parent material.

Rocks [2]

Broadly speaking, rocks include both consolidated (hard) and unconsolidated (soft) mineral and organic deposits of the earth. The mineral rocks furnish by far the greater bulk of material for most soils, but the ultimate product contains important amounts of water, oxygen, and carbon dioxide in chemical combination contributed from other sources. The rocks of the earth are of three principal kinds: (1) Igneous or primary rocks; (2) sedimentary, eolian, and glacial rocks; and (3) metamorphic rocks.

Igneous Rocks

Igneous rocks are formed by the hardening of various kinds of lavas and are composed of different minerals in various proportions. Coarsely crystalline texture is promoted when lavas cool very slowly—usually at great depths below the earth's surface. Finely crystalline and glassy textures develop when lavas are quickly cooled by being intruded between layers or in joints of other rocks or by flowing out over the land surface.

Igneous rocks not only vary in the size of crystals of component minerals, they also vary considerably in chemical character. Some of them are composed almost entirely of quartz, which is distinctly acidic in character, while others contain a high proportion of iron, calcium, magnesium, and other basic elements and are known as basic rocks. Between these two extremes there are a large number of both coarse-grained and fine-grained igneous rocks with varying proportions of acidic and basic elements. The rhyolite-granite group includes rocks dominantly composed of quartz and feldspar with minor quantities of other minerals. The coarse-grained members of

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[2] For more details concerning rocks see Clarke (*65*).[3]

[3] Italic numbers in parentheses refer to Literature Cited, p. 1181.

the group are called pegmatite granites and the finely grained members rhyolites; the glassy members are known as obsidians.

Rocks high in feldspar and iron-magnesium minerals include the coarse-grained syenites and the fine-grained trachytes. Rocks high in feldspars, feldspathoid minerals (similar in chemical composition to the feldspars), and iron-magnesium minerals are known as nepheline-syenites and phonolites. The latter are dark-colored, very dense and fine-grained, and give a ringing sound when struck with a hammer. Other coarse-grained igneous rocks are quartz monzonite, quartz diorite, gabbro, and several others of less importance. Fine-grained rocks include latite, dacite, andesite, and the basalts. The dark-gray andesites and nearly black basalts are especially important sources of soil material. Basalts contain a higher proportion of basic minerals than andesites.

Another important class of igneous rocks comes from volcanoes. Fragments of volcanic materials are blown from craters and spread over the surface of the land or water by winds. Volcanic ash is usually a soft mass of very finely divided glassy or finely crystalline particles. The composition varies as widely as the composition of other igneous rocks, and to a certain extent the fertility of the final soil may reflect this variation in composition. In Puerto Rico and parts of western United States, many volcanic-ash deposits have been stratified by water. Because of their finely divided condition and porous consistence, most volcanic ejecta are easily weathered into soil material.

Sedimentary, Eolian, and Glacial Rocks

Sedimentary rocks are either consolidated (hardened) or unconsolidated fragmentary rock materials deposited by water. They vary in texture from gravelly or stony to the finest clays. The more usually recognized sedimentary rocks are pudding stone or conglomerate, composed of gravels and coarse sands; sandstones, composed of sands of greatly varying composition; clays and shales; and limestones with varying proportions of impurities. In addition to these there are other sedimentary rocks of greatly varying texture which might be called loam stones or silt stones, according to their particle–size composition. Conglomerates and sandstones may be made up almost entirely of quartz, or they may contain a high proportion of such minerals as feldspars, hornblende, pyroxine, and glauconite. Sandstones composed of quartz and feldspar and minor amounts of other minerals are known as arkose, and their chemical composition is similar to that of granite and gneiss. Glauconite, or greensand, is rich in potash, silica, and alumina and easily weathers down to a clayey mass. Soils developed from quartz sandstones are likely to be infertile, whereas those from sandstones containing a goodly proportion of other minerals are more likely to be fertile, although it will be seen from what follows that it is possible for a very poor soil to develop from material rich in plant nutrients. Some sandstones and conglomerates are cemented by silica and weather very slowly, while those cemented by lime ($CaCO_3$) weather rapidly. When iron hydroxide is the cement for sandstones and conglomerates the product is known as ironstone. Many sandstones, conglomerates, and loam stones, such as recent alluvial and lake deposits, are unconsolidated or only weakly cemented.

Clays and shales vary exceedingly in composition. Some of them are highly calcareous, while others contain no lime; some have a high percentage of very finely divided mica, while others contain none; some are composed of finely ground rock flour in which the chemical composition of the original rocks has been changed but little, and others are composed of highly weathered materials. Some clays and shales contain high percentages of silica while others have little or none. All of these factors have a bearing on the ultimate productivity of the soil. For example, productive soils are more likely to develop from highly calcareous clays than from those containing no lime, and from clays with a high percentage of rock flour than from those that have been very strongly weathered over a long period of time. High-silica clays usually have a greater capacity for holding plant nutrients than those of relatively low silica content.

Many productive soils are developed from limestones, some of which are very hard and are composed almost entirely of calcium carbonate or of mixtures of calcium carbonate and magnesium carbonate (dolomitic limestones). Others are soft and chalky and contain a high percentage of clay or sand. These impure limestones merge into the calcareous sandstones and shales or clays. In nature these sedimentary rocks frequently occur in alternate beds varying from thin plates to deep strata several feet in thickness. Frequently siliceous material, such as flint or chert, may be deposited within the limestone. In some places these are a result of deposition from solution in other rocks as well as limestone. Since chert and flint are very hard and resistant to weathering, soils developed from limestone containing them may be very stony. The noncalcareous impurities of limestone usually form the bulk of the material from which soil is formed after the lime has been dissolved.

Eolian (wind) deposits are unconsolidated rocks which are very important soil materials. These consist almost entirely of loess and sands. Loess is composed of accumulations of dusts. It is common near the edges of present or former deserts and along some alluvial flood plains; in some instances deposits reach a thickness of as much as 300 feet. Since the mineralogical composition is extremely complex and variable, there is an abundance of mineral plant nutrients in most loess deposits, including more or less free carbonate of lime. Deposits are usually uniform in texture and color and stand vertically in cliffs where eroded.

Sand dunes are common in many regions, especially along sea and lake shores and within or near the margins of deserts. They may be composed largely of quartz or of fragments of many different minerals. They are not an important source of material for soil formation, but in some places they migrate over the land and destroy crops and even forests. Migrating dunes are common around the southern end and eastern shore of Lake Michigan and in the desert areas of southwestern United States.

Many glacial deposits resemble unconsolidated conglomerates. Some of them are composed of mixed and unstratified gravels, boulders, sands, and clays, while others have been reworked and stratified by water. Some of the most important soil types of northern United States are developed from these materials. The glaciated portion of the United States extends as far south as the Ohio and Missouri Rivers and from the northern Atlantic seaboard to east-central Montana. In addition there are a few isolated areas of less importance in the mountains and valleys of northwestern United States and in Alaska.

Much of the glacial drift is composed of fragments of many different kinds of rocks, and for this reason it nearly always contains fair to plentiful reserves of mineral plant nutrients. In some places, however, such as on the high plateaus of southern New York, it is composed dominantly of rock materials low in the minerals necessary for plant growth. In general the most productive soils in glaciated regions develop from glacial drifts containing a considerable portion of limestone. This is especially true of the soils developed under the forest in the humid regions. Some very poor soils are developed from glacial drift composed largely of noncalcareous sandstone and shale.

Peat is a peculiar type of sedimentary material and ordinarily is considered to be a rock only in a broad sense. Peat is the parent material of organic soils, such as various kinds of muck and peat soils (Bog and Half Bog soils). Some peats are composed largely of woody fragments, some of reed and grass remains, some of sphagnum (peat moss), and some are essentially jellylike or colloidal (very finely divided) materials derived from these plant remains. Many peats are extremely acid in reaction and very low in mineral plant nutrients, although some contain a relatively high percentage of lime where they have been watered by seepage from limestone rocks or calcareous drift.

More soluble sedimentary rocks, such as various kinds of soluble salts, gypsum ($CaSO_4$), and sulphur, are fairly common recent deposits in arid regions, and outcrops of such rocks also occur in some of the older geological formations of humid regions. They may modify the character of soil material but rarely make up the bulk of it.

Metamorphic Rocks

When igenous and sedimentary rocks are exposed to intense heat or to very high pressure, or both, their structure and mineralogical composition are considerably changed. The process is known as metamorphism, and the products are known as metamorphic rocks. Among the most common of the metamorphic rocks are gneiss, quartzite, schist, talc and serpentine, slate, phyllite, and marble. Gneiss is a coarse-grained banded crystalline rock usually derived from igneous rocks of various kinds, although some gneisses are formed through the metamorphism of conglomerates or arkosic sandstones. Gneisses are described as granitic, syenitic, dioritic, etc., according to the minerals of which they are composed and their resemblance to various igneous rocks. Soils derived from them are likely to have properties similar to those derived from the original igneous rock.

Quartzite is formed by the metamorphism of quartz sandstone or conglomerate and is composed almost entirely of quartz. This rock weathers very slowly, and most soils developed from it are unproductive no matter what the climatic conditions.

Schist is the metamorphic product of several kinds of rocks, both igneous and sedimentary, and is commonly derived from sandy clays and shales, through a high degree of metamorphism. Talc, serpentine, and soapstone are metamorphic products of the weathering of siliceous magnesian rocks. Slates and phyllites exhibit a high degree of cleavage and break into thin plates; the former are hard and often dark-colored, while the latter are somewhat softer and contain a high percentage of very finely divided mica or chlorite. Chemical weathering is much slower than physical weathering on them. Clays commonly become hardened into shales. Under heat and pressure shales are changed to slate, phyllite, or mica schist, depending on the intensity of the metamorphism and the composition of the original clay.

Marble is the metamorphic equivalent of limestone. It may be composed either of relatively pure calcite (lime), or it may be dolomitic. Marble includes many impurities corresponding to the orginal impurities in the limestone rock.

Relation of Rocks to Soils

The character of the ultimate soil product derived from any given rock will depend in a large degree on the activity of the other factors of soil formation. A rock may be rich in the minerals essential to plant growth and still produce an exceedingly poor soil. On the other hand, under suitable conditions of climate and vegetation, fairly productive soils may be produced from weathered rocks relatively poor in plant nutrients. Within any local region having only minor differences in climate and vegetation, the kind of parent rock has an important bearing on the ultimate nature and usefulness of the soil. For example weathered gneisses and schists of the Piedmont Plateau of eastern Pennsylvania are the parent materials of very excellent soils for general farming, known as Chester and Manor series.[4] In the same region soils derived from weathered serpentine are unproductive for agricultural crops. The highly productive Sassafras loam has developed from the mixed clays, silts, and gravels of the Coastal Plain of New Jersey, while the Lakewood sand, which is almost useless for crop production, has developed from the quartz sands of the same region.

Primary Physical Weathering of Rocks

Primary physical weathering consists in the loosening and breaking up of the rocks. Joint planes and lines of stratification are the first lines of attack in this process. Daily and seasonal variations in temperature cause expansion and contraction of rocks, and, since the component minerals have different rates of expansion, tension is set up within the mass, and the rock gradually crumbles. Variations in temperature are especially active when rapid and when they pass across the freezing point. This effect is especially important in coarse-grained rocks such as granite.

Exfoliation

Where rocks are exposed at the surface they are subject to almost daily rapid heating and cooling, especially in temperate regions. Since most rocks are poor conductors of heat, the sun warms the outside

[4] In many places in this discussion it seems desirable to make reference to actual soil series or types in the United States by way of illustration. Their location is shown on the soil map at the end of the volume, and their descriptions are given in part 5, Soils of the United States, p. 1019.

shell of rock much more rapidly than the interior, and expansion is correspondingly greater. At night the surface cools and contracts very quickly. The rapid expansion and contraction corresponding to daily changes in temperature ultimately cause rock fragments to peel off in flakes or leaves—a process known as exfoliation. Exfoliation is effective on all dense-structured rocks. Dark-colored, fine-grained igneous rocks, such as basalt, are exfoliated very readily, and the leaflike fragments tend to hold their shape longer than those split off from the coarser-grained igneous rocks. The latter soon crumble into gravelly fragments.

FIGURE 1.—Concentric weathering of fine-grained igneous rocks, characteristic of tropical regions. Near Kilauea, island of Kauai, Hawaii.

Exfoliation is accomplished to an important degree as a result of chemical weathering, especially in warm and humid regions. For example, granitic and fine-grained igneous rocks of the Tropics and sub-Tropics are broken apart piecemeal by the hydrolytic action of water on clay-forming minerals. Water, with some carbon dioxide in solution, finds its way into the joint planes of the rocks and thence into cleavage planes of clay-forming minerals, such as feldspars. Where water comes in contact with these minerals, chemical changes occur (hydrolysis and carbonation), and clays and carbonates, which have a larger volume than the original minerals, form along the contact planes. The formation of these compounds causes expansion, slight in extent but resistless in strength, which breaks up the original rock into fragments and further exposes the unweathered portions to the agents of chemical weathering. In this manner coarse-grained rocks are rapidly reduced to gritty fragments. Fine-grained rocks are more slowly reduced and eventually take the form of concentric rings of weathered, crusty material surrounding a rounded core of fresh rock (fig. 1). In this case chemical weathering nearly keeps pace with disintegration.

In warm-temperate and tropical regions this process is probably more important and significant than the disintegration brought about by expansion and contraction of rocks with temperature changes in cooler regions or by the resistless expansion of ice in the cracks and crevices of rocks in colder regions. In fact, the hydrolytic action of water is an important contributing cause to the comminution (reduction to fine fragments) of rocks and minerals in the temperate zone, both in humid and arid regions.

Ice and Root Wedging

In cool-temperate regions water fills crevices during the warm season and is frozen during colder periods. The resulting expansion, characteristic of ice formation, breaks the rocks into fragments. This process is especially important during late autumn and late winter, when there is much freezing and thawing.

Rocks are also broken apart by the expansion of roots in cracks. Tree roots work their way down from the surface along joint planes and stratification lines and wedge the rocks apart. Smaller roots gain entrance to minute crevices between mineral grains or in the cleavage planes of individual minerals and also help to break up the rocks.

Secondary Physical Weathering

Grinding by Rivers and Ice

The fragments made by primary methods of physical weathering are further broken up by secondary processes. Creeks and rivers collect rock fragments, roll them along their beds, and grind them into finer particles. Deposits of sand and silt in the bends and on the banks of almost any stream bear witness to the importance of this process. The rate of grinding depends very largely on the amount of material suspended in the water and the speed of the stream. The carrying power of water varies approximately with the sixth power of the speed—that is to say, if the speed of the current doubles, the carrying capacity is increased 64 times. The greater the carrying power, the more important the grinding effect along the bottom of the stream. Waves of seas and lakes produce a grinding action among the fragments along the shores.

Materials collected and ground into fine fragments by streams are deposited on flood plains and deltas and, with intermixed materials washed from hillsides of interior regions, go to make up some of the most important soils of the world. The Mississippi flood plain and Delta and the flood plains and deltas of other large rivers of the United States, as well as those of the Yellow and Yangtze Rivers of China, of the Ganges River of India, and of the Amazon of South America, are excellent examples. A very large proportion of the world's population gains its living from the cultivation of alluvial soils. The productivity of alluvial soils has a more direct relationship to the kind of rocks from which the materials were derived than that of most soils, because they are young and only slightly developed and are receiving continual additions of new material. If materials are washed from rocks of low mineral plant nutrient content or from poor soils, they are likely to be poor and unproductive; but large rivers draw their soil materials from such a wide range of rocks and soils that their deposits are likely to make productive agricultural soils.

Glaciers—rivers and seas of moving ice—collect loose rock fragments and not only grind them together to form smaller fragments but also use them as tools for gouging out still more fresh rock from beneath. The grinding effect is especially evident in regions where glaciers are now active. For example, glacial ice on the mountains of northwestern United States flows slowly down into the valleys, where it melts away. Ground rock fragments as fine as flour give the water a milky tint as it flows away from the glacier front, and the rushing streams push innumerable boulders and gravels along their beds away from the glacier. At the present time there are continental glaciers only in Greenland and Antarctica, where they are actively plucking and grinding stones from the rock masses beneath them. During the geologically recent glacial period (Pleistocene) of North America and Europe, however, continental glaciers covered most of Canada, part of northern United States, and much of northern Europe.[5]

It is estimated that these sheets of ice in many places exceeded a mile in thickness. They transported and pulverized an enormous quantity of rock material and deposited it over a very large area. The richest agricultural regions of north-central United States are underlain by materials deposited by these ancient glaciers or by rivers which flowed from their fronts. The glacial invasions of northern United States came from centers in Canada from which most of the unconsolidated material was removed. At the present time large expanses of territory in Canada have very thin soils, because the glaciers scraped the rocks bare and pushed and carried the materials to southern Canada and northern United States. Most of the soils from the Ohio and Missouri Rivers northward to the Canadian border are derived from rock materials deposited by the glaciers or by glacial streams and lakes.

Wind Scouring, Landslides, and Avalanches

In desert and semiarid regions, where vegetation is sparse and winds of high velocity are more or less prevalent, much physical weathering is accomplished by the scouring action of wind-blown sand, which cuts fragments of stone from outcropping rocks of the region. Fragments thus produced are blown into adjacent regions to produce sand dunes and loess.

Some physical weathering is accomplished by means of landslides, avalanches, and soil-flowing (solifluction), especially in hilly and mountainous regions. Landslides and avalanches accomplish much work in steep mountainous regions, as in central Puerto Rico; but they are also fairly common in hilly lands where parent rocks are largely shales and clays, as in northern Wyoming and southeastern Ohio. Freezing and thawing and seepage of water on slopes aid in the process.

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[5]Various estimates indicate that the first part of the glacial period began more than 1,000,000 years ago, and after several advances and retreats of the ice, the last remnants melted away a few tens of thousands of years ago.

Chemical Weathering

Hydrolysis and Solution

Hydrolysis is the predominating process by which the chemical weathering of rocks takes place. Technically speaking, simple solution probably is the first reaction that takes place between water and any kind of rock, but the progress of this action is, in the case of most silicate minerals, infinitesimal when considered independent of hydrolysis. The hydrolysis and solution of most kinds of rocks are hastened by the influence of carbonic acid and various more complex organic acids. Such products are carried out in the ground water. The more finely divided the rock fragments, the more rapid is the action of water so long as it is able to filter through. Among the materials most readily removed in solution are compounds of potassium, sodium, calcium, and magnesium, as well as a certain amount of silicic acid. Solution is especially important on the more soluble rocks such as gypsum, limestone, and rocks containing calcareous cement. Soils can be formed from limestones only when a certain amount of impurities has collected following the removal of calcium carbonate from the rock.

At all stages of the process of breaking up of large masses of rocks into finer material, water is reacting with the minerals, forming secondary products. This is the process called hydrolysis, and it is essentially the exchange of component parts between the minerals and water. For example, when water comes in contact with a simple mineral such as calcium silicate ($CaSiO_3$) some of the mineral dissolves, and the water reacts with the silicate to produce some calcium hydroxide and silicic acid ($CaSiO_3+2H_2O \leftrightarrows Ca(OH)_2+H_2SiO_3$). It will be seen that a change of this sort involves an exchange between constituent parts of the mineral and component parts of the water, resulting in the formation of two substances having properties different from the original mineral and water.[6] Clays are, for the most part, mixtures of complex silicates. They contain varying proportions of alumina, iron oxide, and silica. Some clays are very high in silica, while others consist almost entirely of the hydroxides of iron and aluminum, the silica having been almost entirely removed in solution.

The chemical composition of clay influences to a considerable degree the amount of water held as a part of its constitution. Clays with a high content of iron oxide and alumina usually contain considerably more water than clays relatively low in those constituents and high in silicia. This is not to be confused with the more loosely held water described in another article as hygroscopic water (Water Relations of Soils, p. 897). When water is taken up or is lost in any manner, stresses and strains tend to be set up in the rocks, and this assists physical weathering.

Hydrous oxides of iron and aluminum are each subject to dehydration in varying degrees under different conditions. Such compounds in different stages of dehydration normally occur in certain soils.

[6] More complex phases of hydrolysis, by which various kinds of clays are formed, are discussed in General Chemistry of the Soil, p. 911.

Limonite, geothite, and perhaps the completely dehydrated form, hematite, are found and are usually mixed with a similar group of the hydrous oxides of aluminum. The tendency toward dehydration is particularly marked in some of the tropical regions where highly lateritic soils are formed.

Carbonation (Carbonatization)

In the reaction cited above, the readily soluble calcium hydroxide is easily washed away, but it may react further with the carbon dioxide of the air or of the soil water. In this case, calcium carbonate will be formed, and it will either accumulate in the soil or be washed away according to whether or not there is sufficient water in circulation. In a similar manner carbonates of magnesium and other metals are formed in the soil material or in the soil itself. Carbonation is most rapid in regions of high rainfall, but the products of carbonation are removed so rapidly in such areas that the soil will actually contain fewer carbonates than that developed in semiarid regions.

Oxidation and Reduction

Changes in the state of oxidation of some of the elements, particularly of iron and manganese, take place under certain soil conditions. Mineral powders exposed to moderately dry air undergo little or no change. When they are enveloped by water, however, hydrolysis converts some of the ferrous iron and manganous form of manganese into a solution in the form of slightly soluble hydroxides, among which the iron, ordinarily, greatly predominates. These compounds are capable of taking up oxygen from the air to form more highly oxidized compounds of extremely low solubilities. Such oxidation is often evident from the formation of scums or crusts which have the characteristic color of iron rust and consist primarily of ferric hydroxide, more or lesss dehydrated.

Under certain soil conditions a reverse action takes place. The mere absence of air is not sufficient to cause these compounds to lose oxygen. However, certain organisms associated with the decomposition of organic matter are capable of extracting oxygen from such compounds as ferric hydroxide when air is excluded by water. This change produces an iron compound of greater solubility. When soils are waterlogged for a considerable period significant proportions of the iron may be reduced. These oxidation and reduction changes may play an important role in soil-profile development and in the formation of parent material from rocks.

EFFECTS OF PARENT MATERIAL ON SOILS

Soil material is the product of physical and chemical weathering of rocks and minerals. Since unconsolidated rocks such as sands and clays are nearly always more or less weathered chemically, they may serve as parent materials of soils without having to go through further physical and chemical changes. Soils form directly from them. Parent material may be shallow or deep. It may consist of fragments of widely varying sizes or be of uniform texture; of coarse rock fragments with smaller quantities of finer materials, or the converse; it may consist essentially of a single mineral such as quartz or feldspar or of fragments of many kinds of minerals or of rocks of varying mineralogical composition. The finer materials may be in almost any stage of hydrolysis and leaching with high silica and low alumina content or the reverse. Parent material may be exceedingly resistant to change or may be subject to rapid alteration under the prevailing environment.

Over a long period the general effect of soil-forming processes is to obliterate the differentiating influence of parent material. Many soils may be examined from the surface to a depth of 2 or 3 feet without finding any inkling as to the nature of the parent rock from which the soil material was derived. So-called normal parent materials are mixtures of clays and unweathered minerals and rock fragments of considerably varying composition. These develop into soils the characteristics of which depend almost entirely on the factors of biological activity, relief, climate, and time.

If parent materials are devoid, or nearly so, of mineral plant nutrients it is safe to assume that it will be impossible for fertile soils to develop from them. However, materials of this type are not usual.

Direct Effects

Parent materials have a strong modifying effect in many places on the type of soils developed and more especially on the rate at which development takes place. For instance, quartz and arkose sands are much more subject to the dissolving effect of water than materials high in clays. This is because water passes easily through the materials and there is a smaller proportion of basic elements to be dissolved away. If lime cement is present in these sandy materials or if the rock contains large quantities of lime, removal by solution is very much delayed, but it is not necessarily prevented.

Such rocks as shales, slates, silt stones, phyllites, or mixtures of two or more of them may have the effect of checking internal drainage. This is especially true if the materials have been mixed and compacted by glacial action. For example, imperfectly and poorly drained soils are very common on relatively steep hillsides in New York and New England, because the compact shaly and slaty materials prevent the downward movement of water through the soil. Soils of the Volusia, Erie, and Culvers series are good examples. In most places these occur on gentle to steep slopes, the soils of which would normally be well drained.

In the semiarid and arid regions, parent-material clays sometimes become saturated with sodium and are often very impervious to water. These conditions favor the development of soils belonging to the Solonetz and Soloth groups.[7]

Heavy, waxy clays, whether calcareous or not, are very resistant to soil-forming processes and may retain their essential parent-material nature throughout long periods. Sandy soils develop from very sandy parent materials quite regardless of the other conditions.

[7] References to the names of the great soil groups can scarcely be avoided in this discussion. Their particular morphology and evolution are dealt with later in this article.

Residual Effects

Parent materials in many places have an important residual effect—so-called because it resides or remains in the soil for a long time—on the soil, especially in regard to its productivity for trees, grasses, or crops. Such residual effects are extremely difficult to determine by merely examining a soil in the field without regard to what is growing on it. By examining the parent material carefully, however, or even the parent rock beneath, one can frequently get indications as to what to expect from the soil. For example, in humid regions a soil more productive of the common agricultural crops and grasses may be expected from glacial till containing fragments of limestone than from materials derived entirely from acid shales and sandstones. Forest growth on the former will usually comprise larger individual tree specimens, and the rate of growth is likely to be more rapid than on the acid materials. Crops will be more bountiful, as a rule, on soils derived from more or less calcareous materials than on those derived from more acidic rocks. This is especially true if leaching has not extended to too great a depth. For example, the Miami soils of the North Central States are derived from a glacial till composed of as much as 60 percent of limestone and dolomite materials mixed with granite, gneiss, shale, sandstone, and many other kinds of rocks. Miami soils are productive and maintain much of their native fertility for a long period. They are very responsive to fertilization and good agricultural methods. On the other hand the Lordstown soils, derived entirely from acid shales and sandstones, are far less productive and need considerable fertilization before producing good yields. The Gloucester soils of New England and New York are derived from glacial till composed almost entirely of fragments of granite and gneiss. These soils are responsive to fertilization, but must receive fertilizer applications every year if their productivity is to be maintained. Their natural fertility for crops is far less than that of the Miami soils.

The residual effect of limestone on soils has its limits. For example, in warm-temperate and subtropical regions the prevailing type of weathering has so completely removed the lime and absorbed calcium from the soils that their fertility is greatly reduced. Eventually soil-forming processes overcome the beneficial effects and to a less extent the detrimental effects of parent materials.

Effects of parent material are far more important on young and imperfectly developed soils than on old ones. Freshly deposited alluvium is an excellent example of this fact. Alluvium washed from the soils of the western plains and of the prairie section of Iowa and Illinois have an extremely high natural fertility and will maintain a high state of productivity over a long period of years under suitable moisture conditions. On the other hand alluvium washed from old Red and Yellow soils exclusively has a lower natural fertility and can be made to maintain a similarly high state of productivity only by constant fertilization. Few if any large river systems draw all of their materials from naturally fertile or naturally infertile soils. Alluvium is usually a mixture of both of these kinds of materials and of freshly powdered rock as well. Productivity will vary more or less with the proportion of rich and poor materials, with drainage conditions, and with the adaptability of specific crops to specific soils.

CLIMATE AS A FACTOR IN SOIL FORMATION

The climate is directly or indirectly responsible for variations in plant and animal life, for major soil differences, for the shaping of land masses thrust above the sea by movements of the earth's crust, and to a certain extent for the character of many important rock formations.

Climate influences soils both directly and indirectly. Directly it affects the type of weathering of rocks and the removal and redeposition of materials by water, wind, and glaciers; and it is responsible for the establishment of percolation of water through the soil. Regions of high humidity have more highly leached soils than those of semiarid and desert regions, and for this reason the chemical nature of the soils is radically different. In humid regions most soils are more or less acid in reaction and with few exceptions contain very little free lime (calcium carbonate). On the other hand soils of the deserts are leached but little and usually contain more or less lime and, in many cases, some soluble salts. These effects are in large part directly attributable to climate. In the arctic regions where substrata are frozen throughout the year and where upper horizons freeze and thaw during warmer seasons, there is considerable mechanical mixing of the soil horizons, and the soils remain in a poorly drained condition most of the time.

The most important direct effects of climate are on the weathering of rocks and alteration of parent material. These points have already been discussed in some detail. It is largely this direct influence of the climate on parent rocks which is responsible for the development of enormous areas of Laterite and old Red soils in the Tropics. Many of these materials are true soils, but some of them are the parent materials of soils now formed or in process of formation. In some instances Laterites are true soils, and in others they are merely the parent materials from which new soil profiles are now developing.

The climate within the soil, or soil climate, may be quite unlike that of the air above it. The content of carbon dioxide is considerably higher in soil air than in ordinary air, since it is constantly being produced by plant roots and other living organisms. Except in exceedingly dry soils or in the immediate surface of ordinary soils, the soil air is saturated with water vapor. When covered with vegetation, especially forests, the surface layer of soil is more moist than when cultivated. In fact the clearing of soils and their exposure to the sun may greatly reduce the activity of micro-organisms, especially in the Tropics.

Soil climate, especially that of the surface soil, is profoundly affected by relative atmospheric humidity. Where the average humidity approaches complete saturation (90 to 100 percent) soil climate is more moist than when the average is 60 percent or less. The effects of relative humidity are especially noticeable in China (*405*). On the Kweichow Plateau and in parts of Kwangsi and Szechuan the relative humidity for the entire year averages approximately 95 percent, and soils are in an almost continually moist condition in spite of the fact that the rainfall is less than in some other regions where average humidity is lower. A direct result of this difference in humidity is the formation of Yellow Podzolic soils very similar to those of the southern United States. In the Province of Yunnan, adjoining Kweichow on the west, relative humidity averages from 60 to 70 percent for the year, but the rainfall is greater than in Kweichow. In spite of a greater rainfall, soil humidity is less than that in Kweichow, and as a result the dominant soils belong to the Reddish-Brown Lateritic and Red Podzolic groups. Similar conditions probably exist in mountainous regions of southeastern United States.

In southern United States soil humidity is encouraged in some places by flat or slightly depressed relief, and in these places soils of the Yellow Podzolic group are especially common, whereas on the better-drained areas Red Podzolic soils are dominant. Here topographic conditions have the same effect as differences in average relative humidity. Relative humidity is so high in the British Isles that the soils formed are somewhat similar to those of the United States just west of the Appalachian Mountains, although the annual rainfall of England is comparable to that found in parts of the Great Plains area, where the character of the soils reflects the influence of semiarid climatic conditions.

Effects of Rainfall, Temperature, and Wind

The total rainfall of a given region is not necessarily a measure of the effectiveness of water in soil formation there. Long-continued gentle rains will moisten the soil much more effectively than torrential downpours. Gentle rains soak into the soil, and the water percolates downward without severe run-off, except where the parent materials are almost entirely impervious. On the other hand, torrential rains tend to puddle the surface soil and prevent further penetration by water, and the rain runs off over the surface and into streams. If the land is not protected by vegetation or by erosion-control structures, soil erosion may be severe even on some of the less readily erodible soils. The more gentle rainfall characteristic of western Europe as compared with the United States accounts in part for the relatively small amount of soil erosion in England, France, and Germany. Gentle rains are more characteristic of humid regions than of semiarid and arid climates, where torrential downpours are the rule. Heavy thunderstorms during summer months in humid regions are an exception to the rule, but their effects are partly offset by the absorptive qualities of the soils engendered by dense vegetation.

High average annual temperatures encourage the rapid weathering of parent rocks and soil materials. In general the speed of chemical reactions approximately doubles for each rise of 10° C. in temperature. Hydrolysis, carbonation, and other forms of chemical weathering are extremely rapid in warm regions, especially if those regions are humid. In dry hot regions dehydration is important and hydrolysis, hydration, and carbonation are slowed down. These processes are active only in deeper horizons where soils are protected from the burning rays of the sun and from the evaporation effects of winds. In cold regions, especially if they are humid, soils are frozen during several months of each year, and in arctic regions deep substrata are permanently frozen. Freezing prevents the percolation of water through the soil and so slows down soil-forming processes. In the tundra, processes of soil development are reduced to a minimum. In cool-temperate regions they can proceed actively only during the warmer months. Structure of soil is greatly modified in cool-temperate and temperate regions by freezing and thawing during transitional periods between summer and winter. Freezing and thawing of wet clays tend to form the material into aggregates.

In soil formation, wind acts as a drying agent and as an agent of erosion. Moving air will absorb more water than quiet air, so that in windy regions soils dry out much more rapidly than in regions of calm. The effect is accentuated if the average relative humidity is also low.

Wind erosion amounts to very little in regions of heavy rainfall and dense vegetation, but it is extremely important in the desert and to a less extent in semiarid regions. Winds pick up fine particles of soil and blow them from the deserts to nearby areas where vegetation is more dense and is able to hold soil in place. For this reason deserts are characterized by large expanses of bare rock, by drifting sand dunes, the grains of which are too heavy to be carried far, and by desert pavement.

Desert pavement is an accumulation of gravelly or stony rock fragments on the surface of soils. It is seldom more than an inch or two in thickness. Desert pavement is the coarse residue remaining on the surface after the fine particles of soil have been blown away by the wind. When it becomes thick enough to cover the soil completely it prevents further wind erosion. It will form only in places where the soil is composed of a mixture of fine-grained and coarse-grained materials. For this reason we do not find desert pavement on loess deposits or on silty or clayey alluvial materials. It is not common on soils derived from uniform-grained sandstones but develops readily where soils are derived from conglomerates or interstratified gravels, sands, silts, and clays of alluvial fans.

LIVING ORGANISMS AS A FACTOR IN SOIL FORMATION

Biological Activity

Two of the chief functions of plant and animal life, so far as soil profile development is concerned, are the furnishing of organic matter for the soil and the bringing in of plant nutrients from the lower layers to the upper ones. It may be said that there is no soil without organic matter. The organic-matter content of soils varies widely. Certain peats and the organic mats of some of the forest floors consist almost entirely of organic materials. On the other hand some of the desert soils contain only a small fraction of 1 percent of organic matter. The effects of organic matter upon soil profiles are also extremely variable. The primary source of soil organic matter is the vegetation that develops on it and modifies the color of practically all soils. Higher plants, such as grasses and trees, drop their dead leaves and trunks on the surface, and these furnish an enormous quantity of organic material over a long period. The roots of these same plants permeate the soil, making it more or less porous and penetrating it sometimes to depths of many feet. The decay of roots, especially those of grasses, provides a large amount of organic matter for the soil. Organic material from grass and tree leaves is eaten by worms and mixed by them with the mineral soil.

Deep-rooted plants, such as some of the trees and grasses, bring water from deeper horizons to the surface and into the stems or trunks and the leaves of the plants. With this water there is always a certain amount of dissolved mineral material, particularly of more or less soluble bases, some iron and alumina, a little silica, and many other elements in smaller amounts. When the leaves fall and the plants themselves decay, these minerals are returned to the surface of the soil, and in this manner an important upward movement is established from deep horizons and parent materials to the surface. The process tends to keep the soils in a productive state, and the plants thus assist in the perpetuation of conditions under which they can exist.

If the vegetation is deep-rooted, water will pass through the surface soil more readily than where there are shallow-rooted plants. Thus, other things being equal, there is more leaching under deep-rooted trees than under shallow-rooted trees or grass. Water that falls on the surface tends to be quickly absorbed by these roots, and the water thus absorbed is withdrawn before it can permeate the soil and carry colloids and dissolved materials to deeper horizons. In humid forested regions rainfall is sufficient to overcome this effect, but in grassy areas of subhumid and semiarid regions water that falls on the surface seldom makes contact with water of deep substrata.

The decay of forest debris causes the formation of organic acids of various kinds, including particularly carbonic acid. These acids in solution hasten the leaching processes of soils and soil materials, and basic elements are rapidly leached away. It is the rule, then, rather than the exception, to find more or less strongly acid soils in humid forested regions. Desert vegetation is very scanty, as a rule, and contains little organic matter. Vegetation plays a less important part in the formation of Desert soils than of the soils in humid forested regions and especially in those of the subhumid and semiarid grasslands.

Animals play a role of secondary importance in soil formation, but their total influence is very great. They furnish one step in converting plant remains into soil organic matter, inasmuch as plants directly or indirectly furnish the food for animals and the excreta of the latter are returned to the soil, where they are further transformed. Barnyard manure is an important source of organic matter in agricultural soils, and in some countries human feces are equally important in this respect.

Burrowing animals, such as various kinds of rodents found in nearly all regions, aid in mixing various horizons of soils together and in supplying a certain amount of fresh parent material to surface horizons from which leaching in some soils is taking an extensive toll of plant nutrients. Earthworms feed on soil organic matter and thoroughly mix soils in which they live. They move and enrich many tons of soil to the acre each year, and they thrive especially well in moderately acid to moderately alkaline soils. One of the many indications of potentially productive soils is the presence of plenty of well-nourished earthworms; although in productive soils of arid regions the moisture is frequently insufficient for worms to exist. When such soils are irrigated, earthworms eventually establish themselves and assist in promoting crop production. Following rains in humid regions, pastures and cultivated fields are liberally sprinkled with worm casts, which contribute to the fertility of surface horizons. The burrows of worms and small mammals in many places reach deeply into the earth, and the excavated material is spread out over the surface. When the burrows are abandoned, surface soils, rich in organic material, find their way to deeper horizons as fillings for these cavities. It is possible for roots to make rapid growth through some of these relatively rich materials and to penetrate more deeply into more or less impervious substrata than might otherwise be possible. Animal burrows in desert and semiarid regions are especially noticeable because they are not completely covered by vegetative growth, but they are probably equally important in humid regions where forests dominate the landscape.

Micro-Organisms

Micro-organisms play an extremely important part in the development of soils and their preparation for the growth of higher plants. In some cases micro-organisms tend to encourage the growth of certain kinds of plants, whereas some forms are responsible for the destruction of other plants.

One of the most important functions of micro-organisms is that of changing raw vegetable waste into soil organic matter. Putrefactive bacteria and various kinds of fungi cause the decay of dead leaves and other plant remains and aid in their incorporation into the soil as organic matter. Microscopic animals (protozoa and other forms) live on some of these plant remains and help convert them into soil material. Some nitrogen-fixing bacteria live in symbiotic relationship with plants (usually legumes, such as clover and alfalfa), collect nitrogen from the air, and fix it in a form that can be used by higher plants. Nonsymbiotic nitrogen-fixing bacteria fix a still larger amount of atmospheric nitrogen in the soil. In general, fungi are more abundant in forested regions than bacteria, and their waste products are radically different from those left by bacteria, as indicated in table 1 (*15*). Conversely, bacterial activity is greater in grasslands than that of fungi. Nitrifying bacteria assist in producing nitrates from proteins and other nitrogen compounds, so that they are available for the use of higher plants.

Table 1.—*Chemical composition of fungous and bacterial residues*

Residue	Ether extract	Alcohol extract	Hot-water extract	Hemi-cellulose	Cellulose	Lignin
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Dead soil fungus (*Pseudomonas fluorescens*)	4.63	2.56	8.46	Trace	Trace	14.5
Dead soil bacteria (*Alternaria* sp.)	.54	2.98	5.29	9.32	5.19	29.0

RELIEF AS A FACTOR IN SOIL FORMATION

The influence of relief upon soil formation is due to its controlling effect upon drainage, run-off, and other water effects, including normal and accelerated erosion. Differences in relief may radically affect moisture and air conditions within the soil. Theoretically the water falling on a perfectly level surface of a permeable soil material will be absorbed uniformly into the soil until the latter becomes saturated and will then collect on the surface as a thin sheet. Since perfectly flat surfaces and uniformly permeable soil materials are practically unknown, the rain water collects in depressions, however slight, and penetrates some materials more rapidly than others. Even if parent materials are exactly the same, slight undulations in the surface will encourage the water to drain away from the high spots to collect in the low spots, and soils in the latter situations will receive more water. On moderate and steep slopes the tendency toward run-off is normally greater than the tendency for water to penetrate the soil, and good or excessive drainage is found in such positions. Only during and immediately after rains are these soils wet or very moist. Soils in these positions are subject to more or less severe erosion, especially if they have been cleared of their native vegetative cover, if they occur in arid regions where vegetation is sparse, or if, for some other reason, plant growth is scanty.

Soil profiles on steep slopes are usually not strongly developed, except in some regions of heavy rainfall, warm climate, and dense vegetation. This stunting of soil development is due to (1) rapid normal erosion, (2) the reduced percolation of water through the soil, and (3) lack of water in the soil for the vigorous growth of plants responsible for soil formation. With equal rainfall and similar parent material, the soil climate is more humid on gentle than on steep slopes and still wetter on flats and in depressions.

The degree of profile development taking place within a given time on a given parent material and under the same type of vegetation seems to depend largely on the amount of water passing through the soil. With medium and moderately heavy textured parent materials, therefore, the most strongly developed soil profiles are found on flat areas where there is a sufficiently permeable substratum to carry off the excess ground water slowly. In poorly drained and waterlogged areas may be found strongly developed soils of a special type. Soils of flat areas in the humid temperate zone eventually reach a stage of senility in which they are characterized by leached surface horizons and extremely heavy subsoils of claypan or hardpan types—the Planosols. Convex, gently sloping areas in the same region have a similar sequence of horizons but are without the extremely heavy development in the subsoil. These are sometimes called mature or normal soils. Normal erosion on them is just about sufficient to keep pace with soil-forming processes, so that they neither take on the characteristics of senility nor are sufficiently eroded to be kept in a youthful stage of development. Figure 2 illustrates a sequence of profiles varying in characteristics on account of differences in relief.

It has been pointed out that soils in semiarid and arid climates usually contain more or less lime in the profile, especially in the lower horizons. They also normally contain some of the more soluble salts, such as the chlorides, sulphates, bicarbonates, and carbonates of sodium and other alkali or alkaline earth metals. On convex surfaces, where drainage is good, gradual leaching of rain water removes these salts to deep horizons, below the true solum,[8] where

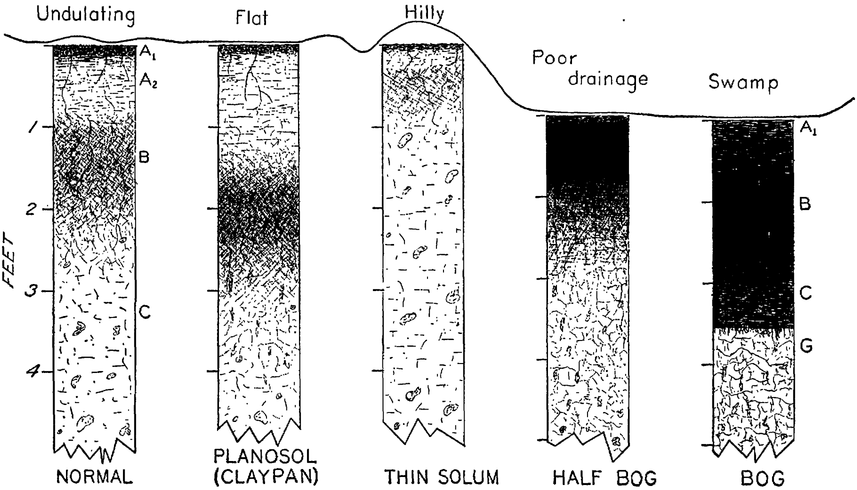

FIGURE 2.—Soil profiles developed from similar parent materials but varying in surface relief. Note that a shallow soil is developed on hilly land because of excessive run-off and erosion; whereas the flat upland has little or no erosion and a highly leached upper soil, with a dense claypan in the lower part of the soil. Examples from the detailed soil classification, reading from left to right, include Miami, Crosby, Rodman, Brookston, and Carlisle soil series (*195*).

they have no bad effect on crops. On concave or flat surfaces, where drainage is imperfect, saline solutions are held within capillary reach of the solum and the salts are precipitated on or near the surface by the evaporation of the capillary water. For this reason, microrelief (minor variations in relief) is extremely important on soils of the semiarid and arid regions, especially where irrigation of the land tends to raise the ground-water level.

In semiarid and arid regions well-drained soils of flats and depressions receive enough moisture shed by soils of steeper slopes nearby to support more vegetation, and hence they accumulate more organic matter. As a result, there are frequently found in depressed but well-drained areas soils characteristic of higher rainfall regions than those in close association with them on slightly higher ground. Microrelief may thus produce a subhumid soil climate in semiarid regions.

Not only is the degree of slope important, in that it affects moisture conditions in the soil, but its direction is also significant, especially on the great plains and deserts. On moderate to steep northerly slopes of the Northern Hemisphere, the sun's rays are much less effective in heating the soil and evaporating the mositure than on southerly slopes. As a result soil moisture is higher on the northerly slopes,

[8] The solum is the true soil or that part of the soil profile that shows the effects of soil-forming processes. It lies directly over the parent material (see Glossary).

vegetation is denser, and the soils are darker. In critical rainfall areas one finds forests on northerly slopes and grasslands on summits and southerly slopes, with correspondingly great differences in soil.

In other places the effects of slope direction may be due to rainfall produced when warm winds are cooled by passing over high hills or mountains (orographic rainfall). For example, summer storms on the Rocky Mountains originate near the crests of ridges and drift eastward, so that more rain falls on eastern than on western slopes. In such regions may be found successively, from the foot of the mountains to the summit, a succession of soil characteristics similar to that found in passing from the arid portion of the Great Plains to the humid forest soils of the North Atlantic States.

TIME AS A FACTOR IN SOIL FORMATION

Time is necessary for the development of soils from parent materials. The length of time required for the formation of a given type of soil depends largely on the other factors involved. Certain acid soils characteristic of humid regions form in a relatively short time on acid materials containing an abundance of quartz sand and a covering of dense forest growth, especially under a cool and very humid climate. Perhaps 100 or 200 years might be sufficient under such conditions. If lime is present in the sandy material the time requirement is greater, and if the texture of the parent material is very heavy, a very long time would be required, because of the difficulty of establishing and maintaining a free downward movement of water through the solum and into the parent material.

Time is a very important factor in the formation of parent material. For example, two soil series in eastern Indiana are both developed on highly calcareous glacial till. The Miami soils are developed from material which has been leached free of lime to a depth of about 30 inches, while the Russell soils, with very similar profiles, are developed on till which has been leached to a depth of about 50 inches. The difference in age of these materials is represented by the difference in time between the deposition of the Early and Late Wisconsin glacial drifts and would probably be measured in thousands of years. The Illinoian drift, in the same State, is leached to a depth of 10 feet or more and represents a still longer time for the preparation of soil material.

It must be remembered, however, that the so-called normal soils are developed on gently sloping land subject to continuous, if slow, geological erosion. Soil and parent-material formation are approximately balanced by gradual erosion.

Soils of flat areas, elevated above present stream overflow, may be much older in point of time and soil development than those on slightly higher and more sloping areas. For example, soils of the Bethel and Delmar series of eastern Indiana (in the Miami-Crosby-Brookston area of the soil map) have much more strongly developed profiles than those of the Miami and Russell series, which are considered normal for the region. Their profiles have not been truncated by erosion, nor, in typical areas, have they received new material. They are old in terms both of soil morphology and actual years. They are classified as Planosols and have characteristic claypan subsoils.

Soil materials of formerly flat and now dissected areas of the Tropics and warm-temperate regions are extremely old in years, even though relatively young from the geological viewpoint. Many, if not most, of them date back to glacial times and even to the more remote Pliocene epoch of the Tertiary period, variously estimated at from 1 to 6 million years ago. Flat, ancient peneplains (areas which have been reduced by erosion almost to base level) of these regions have soils some of which date back, as such, to those ancient geologic times. Many of these soils are in a senile stage of development and are extremely infertile because of long leaching of important nutrients without renewal from fresh parent material.

The time required for the development of a normal soil is probably greater in dry regions than in more humid ones. Where rainfall is light and vegetation scanty, the desert winds are active in removing and redepositing soil materials. Hard lime accumulations many feet in thickness have developed in these desert regions, but the time required must have been great.

Soils of high and steep mountains are normally young in terms of years and stage of development because of rapid erosion, and the age of soils on flood plains is also slight because of the almost continuous accumulation of materials. Many young soils of the mountains as well as of the flood plains are very fertile, but steepness, shallowness, and stoniness in the mountains limit their usefulness for agriculture. Young soils of alluvial flood plains include much of the most productive soil of the world.

One cannot make any useful statement in terms of years, however, regarding the rate of soil formation in general. Some soils have formed very rapidly, in a few years, and others exceedingly slowly. It is also clear that there is no direct relationship between the age or maturity of soils and the age of the rocks underneath.

SOIL-FORMING PROCESSES AND THE ZONAL, INTRAZONAL, AND AZONAL SOILS

On the basis of common characteristics, local soil types and series may be grouped logically into various broader groups as described in the article Soil Classification. These groups fall under the heads of (1) zonal soils, (2) intrazonal soils, and (3) azonal soils.

Zonal soils are those that owe their most important characteristics to the effects of the climatic and biological factors acting on well-drained but not excessively drained parent materials of mixed mineralogical composition over a long period of time. Pedologists speak of them as normal soils.

Intrazonal soils owe their distinguishing characteristics to the overbalancing effects of parent material or relief. In some the parent material is of a special type and is able to outweigh the effects of the biological, climatic, and relief factors. In others relief outweighs other soil-forming factors.

Azonal soils are those that have few or no soil morphological characteristics. Their characteristics are similar to those of the parent materials of which they are composed. These materials have either not been exposed long enough to soil-forming processes or are too resistant to them for soil characteristics to develop. Fresh alluvium, dry sands, and the soils on steep rocky hillsides are the principal examples.

SOIL-FORMING PROCESSES [9]

Zonal, intrazonal, and azonal soils of various great groups owe their characteristics to various soil-forming processes of which the most important are (1) calcification, (2) podzolization, (3) laterization, (4) salinization, desalinization, alkalization, and dealkalization, (5) formation of peat and poorly drained soils, including gleization.

Calcification

Pedocals

The calcification process results in the redistribution of calcium carbonate or carbonate of lime in the soil profile without complete removal of it. Magnesium carbonate accumulates along with the carbonate of lime. The areas so affected are normally those of restricted rainfall—varying from approximately 25 inches or less in the Temperate Zone to approximately 45 inches or less in the Tropics—and the dominant vegetation is grass or brush. Since the rainfall is low, the percolation of water through the profile is not sufficient to remove wholly the calcium carbonate that existed in the parent material or was produced by reaction between carbonic acid and the calcium hydrolyzed from silicate minerals. The usual result is the development of an accumulation of calcium and magnesium carbonates at some point in the profile below the surface, approximating the depths to which surface waters most frequently percolate. Marbut (*240*) called these soils Pedocals (soils with lime accumulation).[10] While this is the normal formation, a calcium-carbonate deposit does not necessarily always occur. A secondary result of calcification is that the calcium tends to keep the colloid (fine clay) in a somewhat granular condition, and there is therefore relatively little downward movement of the colloid in the profile.

It has been possible to arrange a multitude of Pedocal soil series into a few great groups, using their color, organic-matter content, depth, and amount of lime accumulation as criteria for making combinations. The group names are largely of Russian origin, and their application to soils of the United States was first made by C. F. Marbut, who modified some of them. In the present classification further modification seems advisable. They are: (1) Chernozem (black earth); (2) Chestnut soils (dark-brown soils); (3) Reddish Chestnut soils; (4) Brown soils; (5) Reddish Brown soils; (6) Sierozem soils; (7) Desert soils; (8) Red Desert soils.

Chernozems are very dark brown or black in the upper 2 to 4 feet and have slightly acid or slightly alkaline reaction and a nutlike structure. Organic matter is high, and the soils are naturally very fertile. A yellowish-brown or grayish-brown transitional horizon of a few inches separates the dark surface soil from the very calcareous horizon of lime accumulation. The lime is silty in character, includes more or less magnesium carbonate, and occurs as irregular soft masses and vertical streamers, extending to a depth of several feet in many places. Parent material below is less calcareous and in places contains no free lime. Accumulated lime comes partly from lime originally present in the materials and partly from the carbonation of calcium and magnesium silicates.

Chestnut, Brown, and Sierozem soils have prismatic, dark-brown, brown, and light brownish-gray upper horizons, respectively, and progressively less organic matter in the order listed. The thickness of the surface soils also becomes less in the order listed, and the lime accumulation usually reaches its maximum development in the first two, except in cases of extremely old Sierozems and Red Desert soils. All typical members of these groups except the Sierozem and Red Desert soils have little or no free lime at the surface, but the brown horizons in places are calcareous in their lower portions. Calcareous dusts sometimes accumulate sufficiently to render calcareous the surface inch or two. Reddish Chestnut and Reddish Brown soils have a dull reddish tinge in surface horizons and reddish-brown or red heavier subsoils above the horizon of lime accumulation.

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[9] The following pages are somewhat more technical in character than the preceding general discussion and are intended primarily for students and others concerned with soil science.

[10] From a technical standpoint the use of the term "lime" for calcium and magnesium carbonates is incorrect, but the term is very commonly used in this way among laymen and pedologists alike.

Chernozems occupy grasslands with subhumid climate, and Chestnut, Brown, and Sierozem soils occupy regions with progressively drier climate and scantier grass cover. Sierozems have little grass and some small shrubs and are in semidesert regions. Reddish Chestnut, Reddish Brown, and Red Desert soils support a greater percentage of shrubs and less grass than the corresponding groups farther north. True Desert soils have but a scanty growth of perennial shrubs and certain scattered drought-resistant grasses.

Desert and Red Desert soils are in the true deserts—the first in temperate regions and the latter in subtropical and tropical regions. They are usually calcareous to the surface but more so in substrata. Winds remove finer particles from surface horizons and leave a protective desert-pavement cover of small and large rock fragments. In many of the Desert soils the lime accumulation takes the form of hard concretions or stony formations (caliche) and attains a thickness of many feet in places. Physiographic evidence indicates that some of these lime hardpans or crusts were formed in poorly drained depressions tens of thousands of years ago and have become well-drained during a geologically recent cycle of erosion.

According to Nikiforoff's hypothesis (*281*), the reddish heavy subsoil of Red Desert soils is due to weathering of minerals in deeper horizons under the influence of moisture which percolates downward during brief rainy periods. This assumption might also be made in regard to the heavy subsoil horizons of the Reddish Chestnut and Reddish Brown soils.

Black crusts of iron oxide form protective coatings on rocks and pebbles of the hotter deserts and are known as desert varnish.

The calcification process not only connotes the accumulation of lime in the soil but also the adsorption of calcium ions by the colloids. (See General Chemistry of the Soil, p. 911.) Grasses and other plants requiring relatively large amounts of bases, particularly of calcium, bring these bases to the surface and, through decay, replenish the losses of leaching. For this reason the surface soils are seldom strongly acid—usually approximately neutral—and may be even faintly alkaline. When colloids are high in calcium (and to a less extent in magnesium) the reaction will usually range from slightly acid to slightly alkaline, and there will be an abundance of calcium available for crops. Brown Forest soils presumably owe their lack of eluviation and illuviation to this kind of calcification and are limited to areas with a forest vegetation having a particularly high content of bases in its leaves. Rendzinas are also calcified but, in spite of calcareous parent material, do not always contain free carbonate of lime.

Prairie Soils and Degraded Chernozem

Under a somewhat higher rate of rainfall than is characteristic of lime-accumulation soils (Pedocals) the mean flow of water through the profile may be sufficient to produce, under abundant grass cover, a soil profile containing no calcium carbonate accumulation and yet with a high degree of base saturation. Such soils may have some free lime in the parent material. They are the most fertile and productive of the Corn Belt. They exist over large areas, particularly in central United States, and are known as Prairie soils. They have profiles similar to Chernozem and Chestnut soils but do not have any lime accumulation. There is no sharp division in areas or profile characteristics between the soils having a zone of calcium carbonate accumulation and the Prairie soils, which have none. The colloids of Prairie soils are usually high in calcium even though no free lime is present. Furthermore, as rainfall increases and grassland gives way to forests, the calcified soils merge into the Gray-Brown Podzolic, the Red and Yellow Podzolic, and other soils characteristic of forested regions. The northern Prairie and Chernozem soils merge with the Podzols in cooler regions. Reddish Prairie soils contain less organic material than Prairie soils and occur in warmer climates. They grade into Reddish Chestnut soils on the one hand and into Red and Yellow Podzolic soils on the other.

When forests invade the Chernozem grasslands under the influence of changing climate, podzolization becomes active, and the dark color of the Chernozem begins to become lighter, especially in the lower part. Upper horizons begin to take on the character of Podzols and Gray-Brown Podzolic soils before the lime horizon is entirely leached away. These are known as Degraded Chernozems.

The general effect of moderate rainfall, particularly when accompanied by grass cover, is to produce very fertile soils. Calcified soils are usually extremely productive if they receive sufficient water for crops. Even Desert soils of low organic content produce bountiful crops if irrigated and drained.

Podzolization

Podzols and Brown Podzolic Soils

Podzolization is dominant in areas of high humidity and forest vegetation and is one of the most important processes in the formation and modification of the Pedalfer soils. The process comprises two phases. One of these is the accumulation of a peaty mat of organic matter on the surface and removal of clays and iron compounds from an upper to a lower layer, with consequent whitening of the soil layer immediately beneath the surface organic matter. The translocated materials are partly assorted (fractionated), and different ingredients are deposited in different horizons of the profile. Suspended organic matter is deposited just below the bleached layer, together with a considerable quantity of iron and aluminum compounds. Iron compounds are deposited next, often to serve as cementing agents, while clays are carried still deeper by the filtering waters. There is considerable overlap between these horizons. This process results in the formation of members of the great group of soils called Podzols. Typical profiles are usually found on coarse-textured parent material. Table 2 shows the general profile characteristics of Podzol soils.

Table 2.—*General characteristics of Podzol soil profiles*

Horizon	Thickness	Description
1. A_{00}	1 inch or more	Loose leaf litter.
2.-3. A_0	½ inch or more	Fermenting leaves, twigs, and wood. Humified acid organic matter.
4. A_1	¼ inch or more	Dark-gray mixture of acid humus and mineral soil. Usually very thin and entirely lacking in many places.
5. A_2	½ inch to 30 inches or more	Whitish-gray or pale pinkish-gray, highly leached, acid, phylliform (composed of very thin plates or laminae) soil of light or medium texture.
6. B_2	2 to 10 inches	Dark coffee-brown silty or loamy soil containing much organic matter and iron oxides. Sometimes cemented.
7. B_3	4 to 10 inches	Yellowish-brown or brownish-yellow loam or clay loam with little organic matter.
8. B_{31}		Transition and parent material usually more or less acid and sandy, but may be somewhat calcareous in places.

The A_2 and B_2 horizons are usually very distinct, but their thickness varies extremely within short distances. In some places there is a thin transition layer between them. The soils have a low natural fertility but some of them respond well to fertilization.

Under certain local variations in soil climate and where soils have been disturbed within a relatively short time, the whitish A horizon is entirely lacking, and the dark brown B_2 horizon, somewhat lightened in color by admixture with the A_2 horizon, appears directly under the A_0 horizon. The name Brown Podzolic soils [11] is proposed for this group. Gloucester series soils are excellent representatives of this group, while Hermon soils, developed on the same kind of materials, are good representatives of the Podzol group.

The organic layer overlying Podzol soils is usually so strongly acid and of such low base content that bacteria act upon it only very slowly. Fungi usually dominate the microflora. It is possible also that in some cases toxic organic constituents, such as tannic acid, may restrain decomposition. As the acid organic matter slowly decomposes and a part of it dissolves in the presence of iron-bearing minerals, the solution of iron in the ferrous state is promoted. Water carrying such compounds in solution or in a state of dispersion may also carry other organic material or dispersed inorganic soil colloids. As this water percolates through the profile it often encounters soil layers less acid than the surface, and oxidation more readily takes place, rendering the iron less soluble. Such

[11] See Soil Classification, p. 979.

material as may be precipitated under the slightly changed conditions serves as a filter mat to remove still more material from the percolating waters. This may account for the high sesquioxide and organic matter content of the upper portion of the B horizons of many Podzols. The total clay content of this horizon is not usually high, but it is usually composed of a high percentage of aluminum and iron hydroxides and a very low content of silica. Surprisingly large quantities of highly dispersed organic matter are frequently found in the C horizons of such soils.

It is possible for the removal of fine material to take place without much fractionation (partial assortment), and this results in the development of a grayish-brown, whitish, or gray layer in the upper part of the mineral soil without the formation of a very dark brown B_2 horizon. Such a process is also called podzolization, but it does not produce profiles in all respects characteristic of the Podzols. The tendency to fractionation may also be evident without being sufficiently effective to produce typical Podzols. In consequence we have podzolization, as a process, operating to produce modifications in soils of several broad groups wherever sufficient rainfall occurs to produce percolation of water through soil covered with acid organic matter. Podzolization is effective under both coniferous and hardwood forests and in temperate and tropical climates.

Gray-Brown Podzolic Soils

Gray-Brown Podzolic soils of forested humid temperate regions have certain features in common with the typical Podzols, but the profile horizons are less clearly defined. They have a surface covering of leaf litter, usually of deciduous trees; a dark, thin, mild (only slightly or moderately acid) humus, somewhat mixed with mineral soil; a grayish-brown, crumb-structured loamy A_1 horizon and a light grayish-brown or grayish-yellow loamy A_2 horizon; a moderately heavy, nut-structured, yellowish-brown, brown, brownish-yellow, or reddish-brown B horizon, becoming lighter-colored with depth. The total depth of the solum varies considerably but seldom exceeds 4 feet.[12]

Parent materials of Gray-Brown Podzolic soils cover a wide range of weathered rocks and minerals, and their character has an important bearing on their ultimate agricultural productivity. Perhaps half of the region of Gray-Brown Podzolic soils in the United States was formerly covered by glaciers, and these materials are variable in composition. Miami soils of Ohio, Indiana, Michigan, and Wisconsin and Honeoye soils of New York are among the best-known of the Gray-Brown Podzolic soils derived from glacial till, while the Chester and Sassafras soils of the northern Piedmont and the Coastal Plain, respectively, well represent the unglaciated members.

The Red and Yellow soils of warm regions, and even Laterites, also are subject to the podzolization process, but the decomposition of organic matter is still more rapidly accomplished and the leaching of bases is more complete than in Gray-Brown Podzolic soils. The fractionation of the colloid is still less marked than in either the Podzols or Gray-Brown Podzolic soils. That is to say, the chemical composition of the mineral colloids of all horizons does not vary greatly. The surface horizons may, however, be as completely bleached as the bleached horizons of typical Podzols. In fact, this is very commonly the case, even in the soils of tropical regions, provided the parent material contains at least a moderate content of quartz sand and silt.

Laterization

The soil-forming process called laterization is essentially the progressive hydrolysis of rock minerals, and its full development results in their conversion to silicic acid, aluminum hydroxide, and iron hydroxide or their more or less complete dehydration products—the Laterites. Since in general silica is more rapidly removed by solution than are iron oxide and alumina, a fully developed Laterite may consist of only aluminum and iron hydroxides, although the process is normally not complete in any soil. The ultimate decomposition products contain very little acidic material; and, consequently, have little base-holding capacity. The Laterites are normally very deficient in plant nutrients and can only be used

[12] For further details see Baldwin (*23*), Marbut (*240*), Kellogg (*145*), and Baldwin, Mark, some characteristic soil profiles in the north central states. Amer. Soil Survey Assoc. Bull. 7: 122–132. 1926. [Mimeographed.]

for the production of agricultural products by frequently repeated applications of fertilizers, the phosphate portion of which is rapidly rendered unavailable. On the other hand, since high temperature and high humidity favor plant production and also hasten laterization, Laterites and lateritic soils are often productive when fertilized or when conditions favor the accumulation of much organic matter on the surface. The fertility resulting from the latter condition rapidly disappears under cultivation.

Laterization, in its strictest sense, is a process of soil-material development—a process of rock weathering resulting in the formation of lateritic clays on which the podzolization process acts to form podzolic Red and Yellow soils characteristic of humid warm-temperature and tropical regions. Lateritic clays are basically red, with reticulate mottlings of red and light gray, buff or whitish; but some of them, where drainage conditions have always been nearly perfect, are a fairly uniform red color. They are usually thick and may reach a depth of as much as 100 feet in places where weathering has been active for many thousands of years. They develop from many different kinds of rock materials, including dark-colored fine-grained igneous rocks, granites, shales and loamy sandstones, arkose, and limestone residuum.

Soils derived from lateritic materials usually are more or less podzolized, especially if they contain moderate or high proportions of quartz sand or silt. Red Podzolic soils, of which there are many in the southeastern United States and in the West Indies, have up to an inch or two of leaf litter on the surface, with matlike development in places; a gray or dark brownish-gray humified mineral soil (A_1) up to 2 or 3 inches thick, a yellowish-gray, or light pinkish-gray more or less sandy A_2 horizon several inches thick; a red or brownish-red granular-structured clay B horizon, 1 to 3 feet thick, and reticulately mottled lateritic parent material, already described.

Yellow Podzolic soils develop under more humid soil conditions than the Red Podzolic soils, either because of impaired drainage or because of a higher atmospheric humidity, coupled with a high rainfall. The A_2 horizon is grayer and deeper in many places than that of the Red Podzolic soils and the upper B horizon is pale yellow instead of red. The lateritic parent material usually has a higher proportion of yellow in the color pattern.

Some Red and Yellow Podzolic soils are only slightly acid in reaction, while others are very strongly acid.

Laterite is supposedly the ultimate product of lateritic weathering, but this theory has not been proved conclusively. In many places it seems probable that kaolinlike (halloysitic or kaolinitic)[13] clays, with a silica-alumina molecular ratio of 2, are the ultimate stable product. The Laterite originally described by Buchanan (*296*) in India is a reticulately mottled, red, buff, and whitish clay from which some of the lighter-colored clays have been removed, leaving a more or less cellular structure. These clays harden into rock on exposure to the air. They are composed very largely of the hydroxides of aluminum and iron.

The ferruginous (high-iron) Laterites of Cuba and Puerto Rico (Nipe series) and of the Hawaiian Islands are uniformly dark brownish red in color, granular in structure and porous in constitution. They contain higher percentages of iron than normal Laterites. There are occasional seams of cellular ironstone in them and many shiny black iron-manganese concretions. These soils absorb water very readily, with little or no swelling, and can be plowed immediately after heavy rains. They have extremely low natural fertility and are subject to drought. True Laterites seem to have been developed under tropical conditions with alternating seasons of high rainfall and drought. They have been found in Puerto Rico and the Hawaiian Islands but are not known in the United States.

Soils in which the laterization process has become markedly evident but has not reached completion are known as lateritic soils. Their best-known representatives in the United States are the Red and Yellow soils of the humid South and Southeast, and they are very important in the West Indies. Most of them have been modified by podzolization. These soils are characterized by a colloidal fraction whose molecular ratio of silica to alumina is approximately 2. Material of this composition is very inert, having properties in common with those of the commercial clays known as kaolin or china clay. Such soil colloids sometimes have a submicroscopic crystalline structure characteristic of the clay minerals known as halloysite and kaolinite.

[13] Kaolin is common china clay, used for making chinaware. This clay contains 2 molecules of silica (SiO_2) for each molecule of alumina (Al_2O_3).

In most areas where Laterites or lateritic soils are dominant, there usually exist areas of less strongly developed soils in which, by reason of rapid erosion, or of deposition of alluvium or volcanic ash, fresh minerals are exposed to decomposition. Under such conditions, even in tropical areas of high humidity, a very complex mixture of soil types may be found.

Formation of Peat and Poorly Drained Soils (Gleization)

When soil parent material is nearly impervious to water or is so located topographically that water stands continually at or slightly above the surface, the plant growth, as it perishes seasonally, builds up a body of organic material known as peat. Peat deposits in bogs are particularly abundant in cool, moist climates where conditions are favorable for the growth of sphagnum and other mosses, but they also occur in warm-temperate and tropical regions and are sometimes composed largely of wood, grasses, or reed remains. Great peat deposits are found in Florida, Georgia, North Carolina, and Puerto Rico, as well as in the northern tier of States. Muck is peat in a more advanced stage of decomposition and usually has a greater mineral content. It is usually black or very dark brown in color, and some varieties produce high crop yields. Peat and muck are known collectively as Bog soils.

Under alternating wet and moist conditions iron compounds are reduced to soluble forms and the solubilities of calcium, magnesium, and manganese are increased. The usual effect is to produce a gray or bluish layer in deep soil horizons and mottling of yellow, brown, and gray streaks along cracks and root channels of upper horizons. In sandy material there may be produced soils which closely resemble Podzols in general character. These are known as Ground-Water Podzols, and in many places they have a hardpan of organic matter or ironstone at the mean level of the ground water. The process results in the formation of a wide variety of soil types intermediate between peat and Ground-Water Podzols. These include Wiesenböden (Meadow), Half Bog, and various Planosols, as well as Tundra and Alpine Meadow soils. Most imperfectly and poorly drained soils have more or less strongly developed profiles differing, as already indicated, from the normal soils of their regions. The bluish or greenish waterlogged horizons are sometimes called glei or gley, and the process by which they are formed is sometimes called gleization. In tropical regions poorly drained Ground-Water Laterites are developed under fluctuating wet and dry conditions. They are especially common on nearly flat areas.

Imperfectly drained soils in which the ground water is constantly draining away tend to become gray instead of bluish or greenish in deep substrata, and these soils in many places are better suited to cultivation when drained. This horizontal leaching and eluviation may be regarded as a phase of podzolization. The podzolized rice paddy soils of China are excellent examples of the combined effects of gleization and ground-water podzolization. Usually it does not pay to drain very strongly acid wet soils for cultivation, but those containing any appreciable percentage of lime are often quite productive when drained. Rice will usually produce well, if fertilized, on soils having a very wide range of acidity, but yields are likely to be low if bluish or greenish horizons (true gley) closely approach the surface.

Salinization, Desalinization, Alkalization, Dealkalization

Salinization

Salinization is the process of accumulation of various kinds of salts in the soil, including sodium chloride, sulphate, bicarbonate and carbonate, calcium sulphate (gypsum), and chloride; and sometimes magnesium sulphate and chloride or potash salts also may be present. When these various kinds of salts occur in appreciable quantities in the soil they are popularly known as alkali. White alkali is composed of one or all of the salts listed except sodium carbonate. Sodium and potassium carbonate are known as black alkali because they dissolve and disperse the organic matter which diffuses through the soil and colors it dark brown or black. The presence of sodium carbonate also tends to strongly disperse the inorganic colloidal material when water is present. As this dispersed mass of organic and inorganic materials dries, it forms a jelly and later a structureless impervious mass. It serves as a highly effective cementing agent when mixed with the coarser soil grains. Salinization can occur on practically any kind of soil and gives rise to the development of saline soils—sometimes called Solonchak.

Saline soils are most common in imperfectly or poorly drained areas of semiarid and arid regions in depressions and in seepy spots. They are fairly common in old lake bottoms in these regions and on low alluvial deposits along seacoasts, even in humid regions. The salts are concentrated from the decomposition products of rocks that may contain only small quantities of such constituents as chlorine and sulphur, together with more abundant quantities of the basic elements sodium and calcium.

Salts usually accumulate in the soil by the evaporation of slightly saline capillary water or by the evaporation of salt water from the surface, as along the borders of salt lakes. In some cases salts are deposited in the subsoils—sometimes several feet underground. This is because the capillary movement is not usually very active more than 6 or 8 feet above the surface of ground water and evaporation takes place in the soil air. In some cases the very coarse texture of the soil prevents capillary water movement and evaporation takes place in the pores of the soil.

There are many different combinations of salts of various kinds in saline soils. In many of them sodium chloride is the chief salt, with only very small proportions of others. In others sodium sulphate, sodium carbonate, or some of the salts of calcium and magnesium may dominate, or the salts may be a mixture of approximately equal quantities of each. In some cases complex double or triple salts, such as hanksite—a compound containing sodium sulphate, sodium carbonate, and potassium chloride in definite proportions—may be present. If the salts are composed almost entirely of compounds of sodium, with possibly some potassium and other salts in lesser quantities, there is a tendency for the soil colloids to approach saturation with sodium and for the soil to become a sodium Solonchak. With a more abundant water supply these soils develop into alkali-claypan types sometimes called Solonetz. On the other hand, if alkaline-earth salts, such as calcium sulphate and chloride, are present in large quantities there is a tendency for the soil to change over into one of the normal zonal types such as Chernozem, if and when the salts are removed under improved drainage conditions.

Saturation of soil with sodium salts results in large amounts of sodium being absorbed by the colloidal clay. When such clays are leached by fresh water and the excess salts removed, hydrolysis of the sodium clay results in the formation of sodium hydroxide and later carbonate which causes individual clay particles to separate from one another when sufficient water is present, to form a jellylike mass. This is known as deflocculation and is a very common phenomenon leading to bad physical condition in soils after the greater part of the salts has been leached away.

Vegetation on saline soils is usually rather sparse and of specialized types, particularly if the percentage of salt is high. When there is more than 0.2 percent of the "white salts," most economic crop plants will be injured, and certain specialized types of vegetation will begin to appear. Very few agricultural crops will produce well when there is more than 0.5 percent of salts, but the salt-loving vegetation will be fairly abundant on such soils. These salt-loving plants are known as halophytes. There are also some plants which grow well on saline soils but almost equally well on normal nonsaline soils. These are described as being salt-tolerant. Surface soils with more than 3 percent of salts seldom produce plants of any kind except deep-rooted varieties that were established before the accumulation of salt took place and have been able to extend their roots to deep levels where salt concentrations are not so great. Aside from the actual concentration of soluble salt present, sodium carbonate tends to produce such a strongly alkaline condition (high pH) of the soil solution that few plants can survive when more than a few tenths of 1 percent of this constituent is present.

Desalinization and Alkalization

Theories concerning these processes are many, and at present it is not known with certainty which are correct and which are wrong. The following theory is most commonly accepted, in whole or in part, by pedologists: When drainage conditions on saline soils are improved and when they are irrigated or receive fresh water from some other source, the salts are gradually dissolved and leached away. As long as there is an abundance of salts in the soil the colloidal clay materials are held more or less aggregated, and the soils are usually sufficiently porous for water to pass through rather readily. So long as sufficient salts remain, this structure is maintained, and the sodium-saturated colloids are not able to hydrolyze. If there is an abundance of calcium in the soil in the form of soluble salts or as finely divided lime the condition of good percolation is maintained, and the soil gradually changes over to one of the zonal types, such as Chestnut or Chernozem. If, on the other hand, the calcium content is low and the sodium content high, the sodium clays will hydrolyze to form free sodium hydroxide as soon as the greater part of the salts has been removed. This results in the deflocculation of the colloidal particles, and the soil becomes sticky, jellylike, and impenetrable to water, thus restraining the further improvement of such soils or actually rendering them unproductive even though the soluble salt content may be below the percentage limit normally toxic. The soil solution becomes very strongly alkaline, and very few plants can survive under these conditions. Accompanying the deflocculation of the clays, organic matter is dispersed and colors the entire soil mass dark brown or black. In this stage the soil is popularly known as black alkali. Some sodium carbonate is formed through the reaction between sodium hydroxide and carbon dioxide of the air.

Following the deflocculation of the clays, there is a tendency for them to migrate downward through the soil and to collect in slightly lower levels, leaving a coarser-textured material at the surface as a very thin coat. The soil in this stage of development is sometimes described as an alkali-claypan type. The clay horizon is extremely heavy and plastic when wet and very hard and columnar or prismatic in structure when dry even though the percentage of clay may not be very high. The columns or prisms tend to become rounded at the top, and the gradual horizontal movement of water over them during wet weather tends to cause the development of a white or light-gray leached silty layer from which organic and mineral colloids have been removed by the water. Among pedologists these alkali-claypan soils are known as Solonetz, a term which has been adopted directly from the Russian.[14] The process is known as solonization among some pedologists.

The typical Solonetz has many points in common with the claypan soils (Planosols) of the Gray-Brown Podzolic soil region and with those of the Red and Yellow Podzolic soil region as well. They may be compared, for instance, with the Crosby soils of Ohio, Indiana, and neighboring States. The Crosby soils have claypans which do not, however, have well-defined columnar structure in the subsoil, but there is an accumulation of grayish silty material in the lower part of the A horizon. The Crosby soils are acid to a considerable depth and differ in most other respects from the Solonetz.

Many objections have been raised to this theory because a number of Solonetz soils examined have contained a rather high content of absorbed calcium, and in some cases of magnesium. This seems to be in conflict with the theory inasmuch as high calcium content is supposed to prevent the deflocculation of the colloidal material of soils. Some hold the theory that magnesium has an effect similar to that of sodium, so that there might be magnesium Solonetz as well as sodium Solonetz. Others believe that the magnesium ion has an effect similar to that of calcium and should, therefore, tend to keep the soil in a more or less granular condition and prevent deflocculation. Up to the present time no one has satisfactorily proved the theory of the formation of Solonetz. It is obvious from the facts available that the soils cannot be strictly defined in chemical terms, especially in regard to the base-exchange complex. It seems obvious that the definition of Solonetz should be a morphological one and should apply to soils having the characteristics described above. It was on this basis that it was originally described, and the morphological characteristics are far more important to the farmer, to the road builder, and to the soil surveyor than slight chemical differences.

Where Solonetz soils occur in imperfectly drained positions it is reasonable to suppose that there may be some variation in the absorbed ions from one season to another. When the water table is high and the weather dry, moderately large quantities of salts will be brought up from the subsoil and deposited in upper horizons. These salts may be rich in sodium or potassium, or they may contain

[14] Although the term Solonetz has long been used in the Union of Soviet Socialist Republics, there appears to be some confusion even there regarding a satisfactory definition for this group of soils. In the usage of the term sometimes a chemical definition is implied, and sometimes the definition appears to rest more specifically on morphological characteristics. It is not surprising, therefore, that some confusion regarding the use of this term has occurred in some of the Western States where Solonetz or Solonetzlike soils occur. There is particular need for further chemical and morphological work on this group of soils occurring in widely scattered localities, in order that chemical character and morphological features may be correlated.

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more or less magnesium and calcium. Their content will doubtless have some bearing on the character of the absorption complex. During protracted rainy periods, an abundance of fresh water will tend to remove part of the salts, and it is easy to imagine that some of the salts would be removed more rapidly than others according to their solubilities and according to the strength with which some ions are held by the soil colloids.

Solonetz soils are most abundant in semiarid regions where they receive light accumulations of wind-blown calcareous dust from drier regions. Is it unreasonable to suppose that the calcareous dusts thus accumulated may, in the long run, result in an exchange of ions in Solonetz soil, the sodium being replaced by calcium after a long period of exposure to these conditions? Obviously the whole problem is still very much in a state of flux, and it may be necessary to make many chemical analyses of samples taken from the same spots under different weather conditions and from widely separated areas and under considerably varying climatic conditions before the details of their genesis are discovered.

It is well known that Solonetz soils begin to form where saline soils, high in sodium salts and low in calcium salts, are irrigated and drained. For this reason it is unwise to initiate irrigation projects on saline soils unless there is a high content of lime, gypsum, or other calcium salt in the soil, or unless these are added at the time irrigation is undertaken or are present in the irrigation water.

Dealkalization

When drainage is improved on Solonetz soils dealkalization takes place and the excess sodium carbonate and a great deal of the absorbed sodium is gradually removed. Under these conditions the whitish silty layer, characteristic of the A_2 horizon of Solonetz, becomes gradually thicker. It follows the cracks between the columns to considerable depths, the tops of the columns are gradually bleached, and the collodial clays removed to lower depths. Eventually the upper layers become moderately or strongly acid in reaction, even though parent materials and lower B horizons may remain neutral or alkaline. The soil formed by the dealkalization process might be called dealkalized-claypan soil. It is commonly known among pedologists as Soloth, another word taken directly from the Russian.

Theoretically Soloth soils gradually change to normal soils of the region in which they occur after the normal vegetation has been able to establish itself on them. For instance in a region of Chernozems grasses spread to the Soloth soils, and their roots penetrate deeply to layers rich in lime; and calcium, brought to the upper horizons in the roots and in the leaves of the grass, is deposited in the soil. Calcium combined with the organic matter is in a relatively insoluble form and aids in the aggregation of the fine soil material. In this form it cannot easily be removed in solution or colloidal suspension; thus the light-colored Soloth soil gradually becomes darker and darker until it develops into a true Chernozem. Undoubtedly this process will take a very long time if it actually takes place. In a similar manner, Soloth soils are supposed to change gradually to Chestnut and Brown soils in regions characterized by these types. To what extent theory and fact correspond in these respects is not fully known. The process by which Soloth is formed is sometimes known as solodization.

Transitional Soils

It is not possible to pigeonhole every saline and alkali-affected soil neatly into the groups just discussed. There are many transitional stages between each of them individually and between all of them and the zonal soils with which they are associated. Soils of this general group have a wide variety of common names among farmers. They are known, for instance, as scab spots, slick spots, buffalo wallows, and by many similar names.